Esperimenti nello spazio

Matteo Tenti
(INFN - CNAF)

19/05/2016

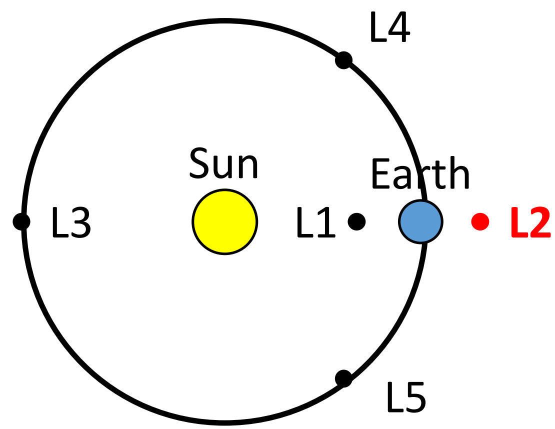
Workshop di CCR

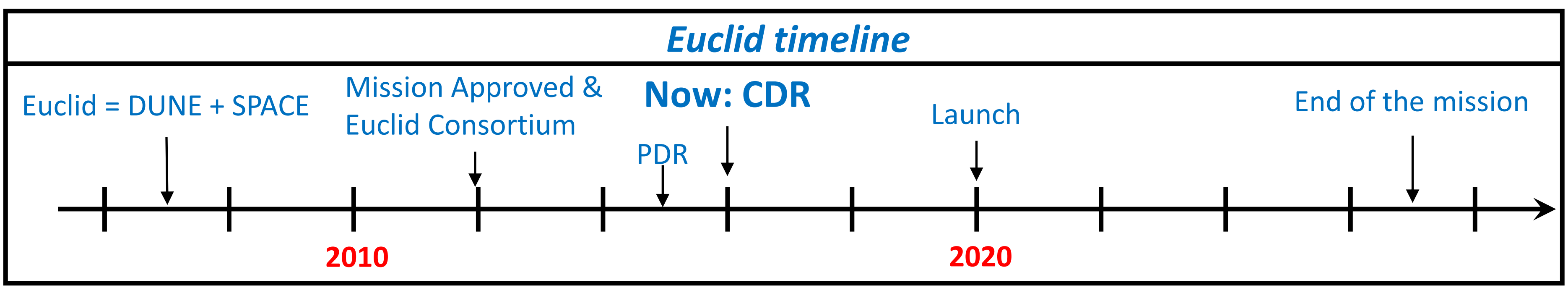
La Biodola, Portoferraio (Li)

- **_Euclid_** **_(Matteo Tenti)_**
- **_LSPE_** **_(Francesco Piacentini)_**
- **_DAMPE_** **_(Domenico D'Urso)_**
- **_PAMELA_** **_(Francesco Cafagna)_**

Euclid mission

- Euclid is **medium class** mission of ESA **Cosmic Vision** program (2015 - 2025)
- **Launch: 2020** from ESA spaceport in Kourou (French Guyana) with Soyuz ST-2.1B rocket
- Orbit around the Lagrangian point **L2** of Sun-Earth system
- Nominal mission: **6 years**

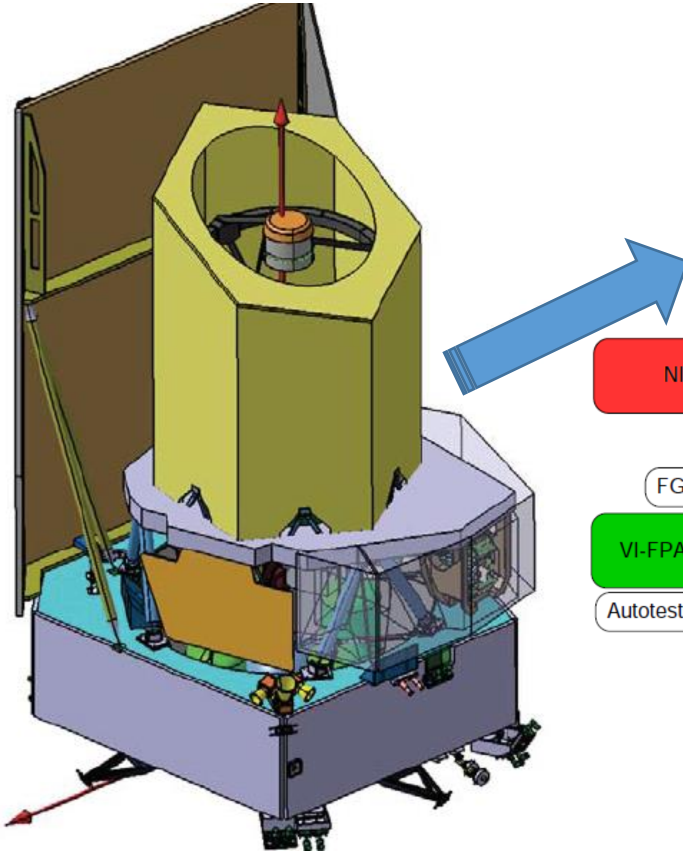


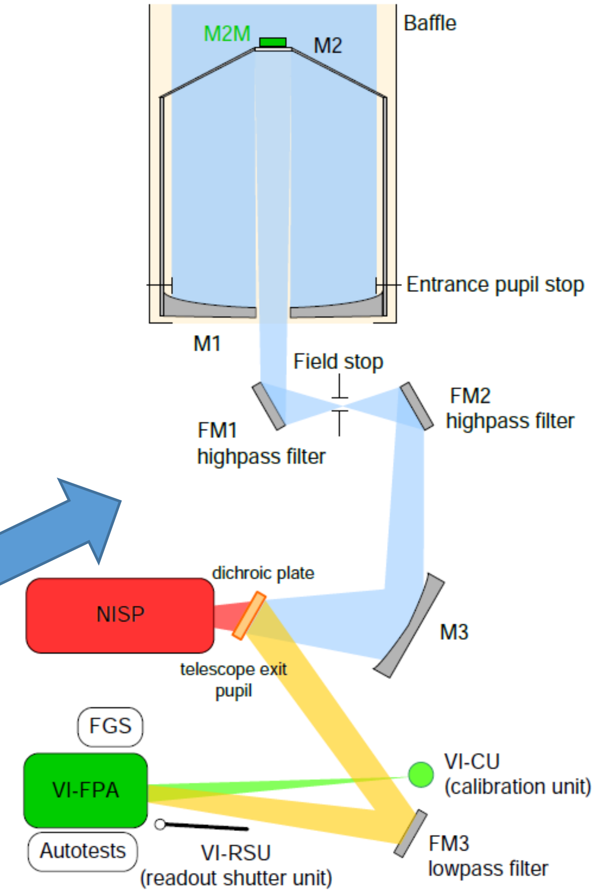


Euclid Payload

1.2m diameter telescope

- **VIS: Visual Imager (36 CCDs)**
- **NISP: Near-Infrared Spectrometer and Photometer (16 H2RG)**
- **Two wheels:**
  - **filters for photometry**
  - **grisms for spectroscopy**





Euclid Physics

- *Why*: understand the physical **origin of the accelerated expansion** of the Universe

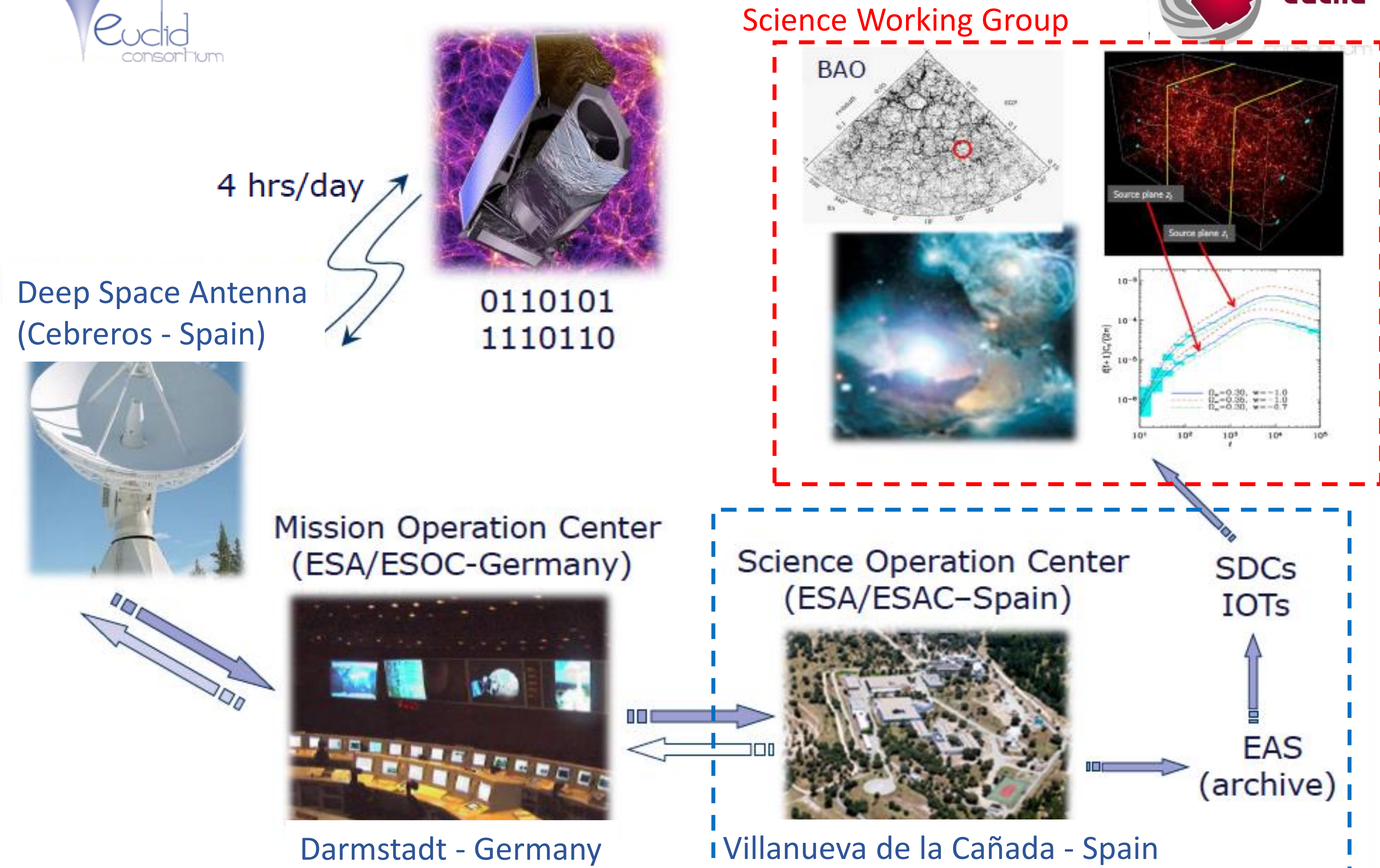
- *How*: **mapping matter** distribution at different redshifts (i.e. looking ~ 10 Gy back in time)

  - **Dark Energy equation of state** $[w = p/\rho]$:
    cosmological costant $(w = -1)$ or **scalar field?**

  - **Structures' growth rate** $[f(z) = \Omega_m(z)^\gamma]$:
    general relativity $(\gamma = 0.55)$ or **modified gravity?**

  - **Neutrino mass & effective numbers**

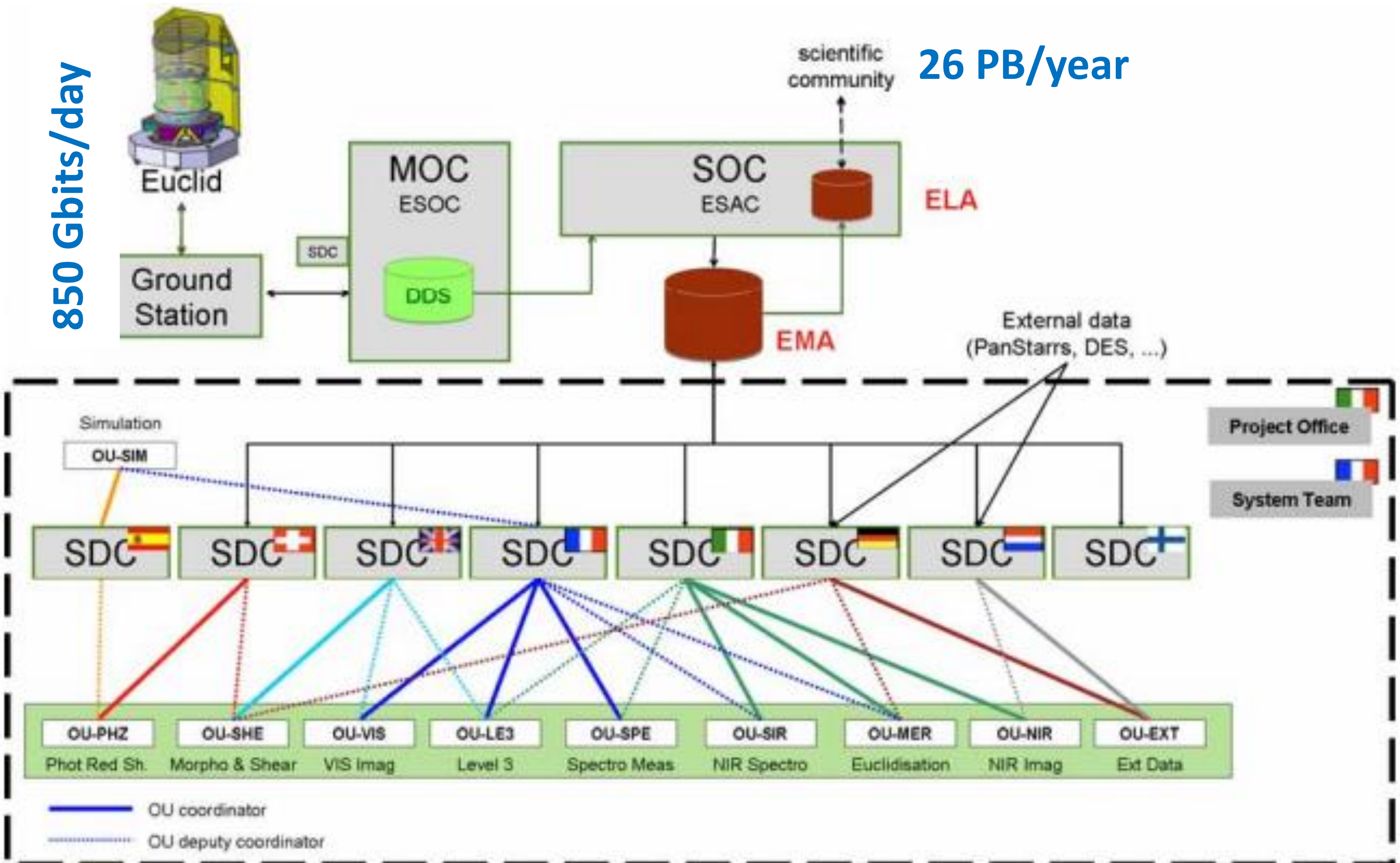
Euclid Data Flow



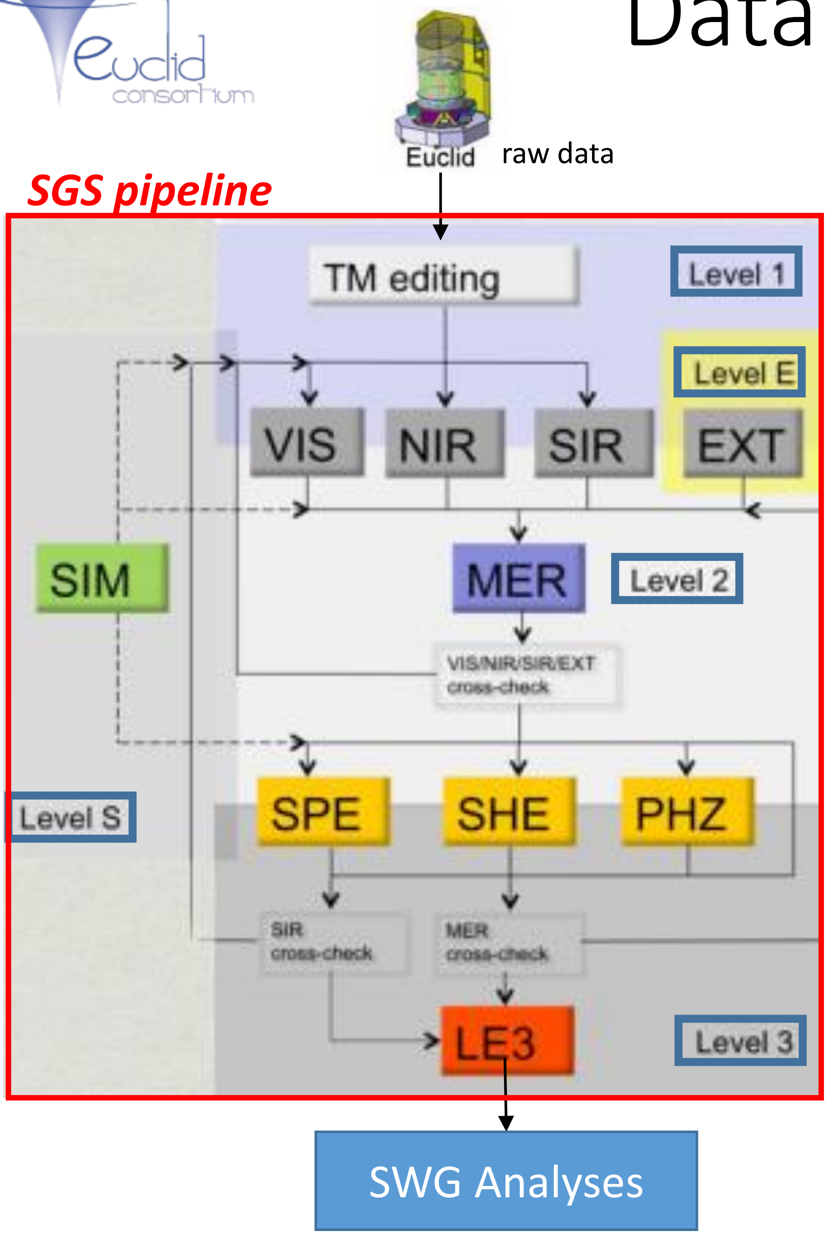
Science Ground Segment

Science Ground Segment

- Euclid data are managed by the **Science Ground Segment (SGS)**



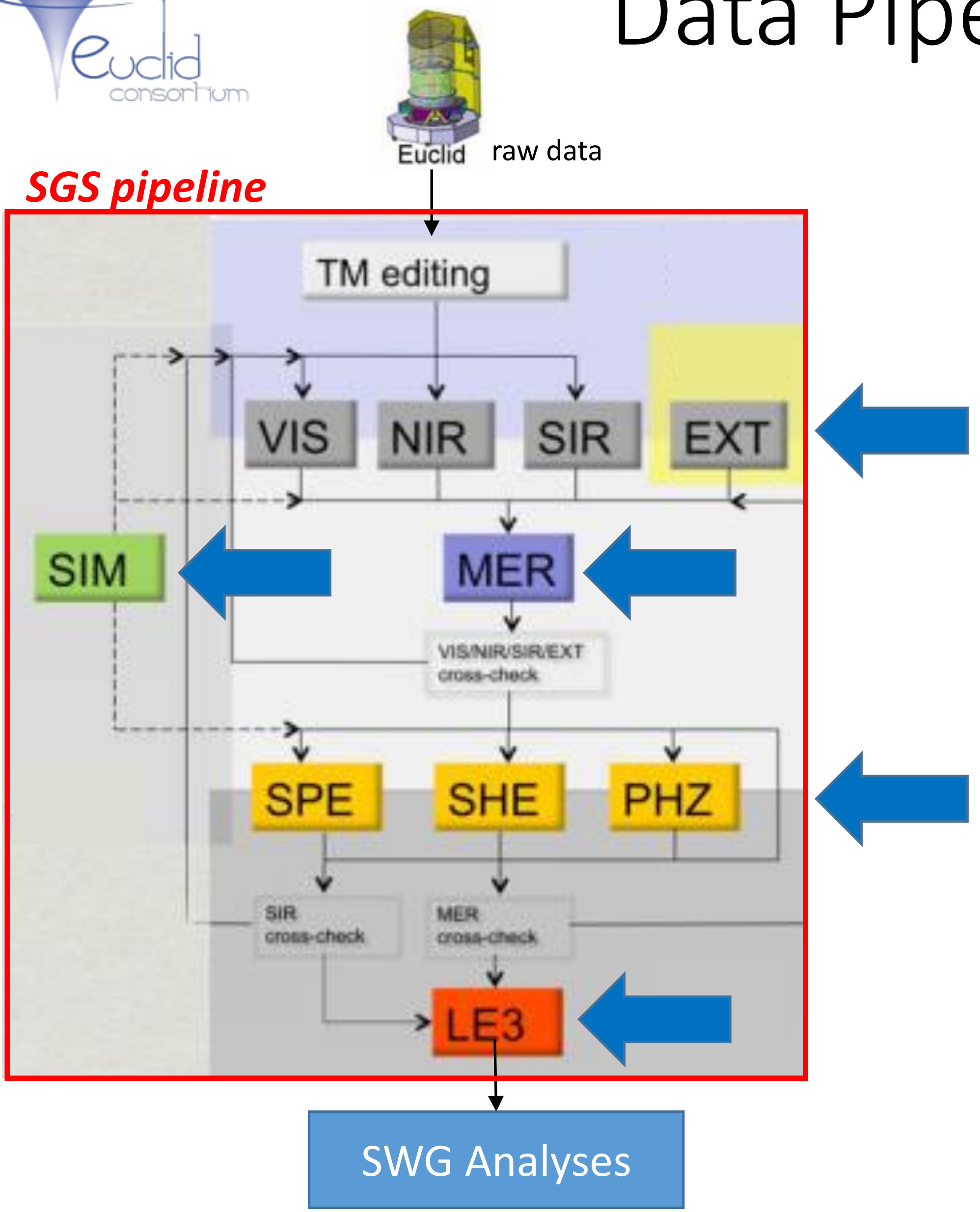
Data Pipeline



Data are organized in different **levels**

- **Raw data** from satellite
- **Level 1**: edited telemetry
- **Level 2**: calibrated signal from instrument
- **Level 3**: physical observables (redshift, shear) reconstruction
- **Level Q**: quick release
- **Level E**: external data from ground-based experiment
- **Level S**: simulation

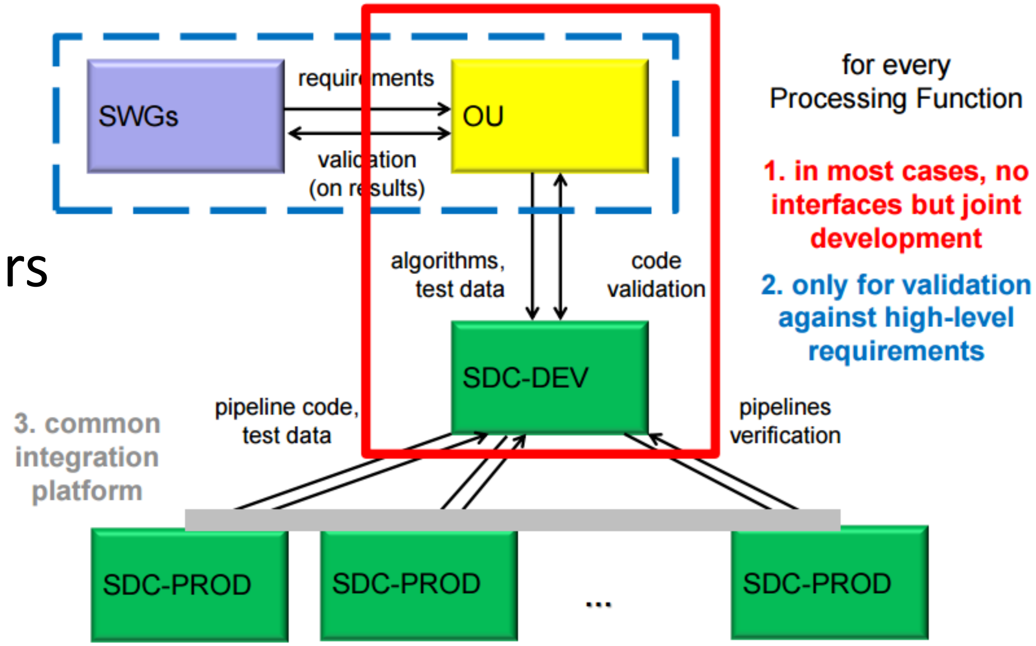
Data Pipeline



- Pipeline elements are the **Processing Functions** (PF), each having a specific task
- Each PF is mainly (*but not exclusively*) related to one Science Data Centers (SDC)

Processing Functions

- **Designed** by Organization Units according to the requirements from Science Working Groups
- **Developed** in collaboration between the Organization Units and Science Data Centers
- **Integrated** and **Run** by the Science Data Centers
- **Continuous development and implementation** during the entire mission



Architecture Concepts

- **Data-centric** information system:
  - ***Move the code***, *not the data*
- **Centralised** information repository
  - *separation of metadata from data*
- **Distributed** data and processing
  - *each SDC is both a processing and a storage node*
- **No dedicated** SDC
  - *each SDC runs the same code through* ***virtualization*** (CernVM, Docker, …)
- **MapReduce** model: **μpipelines** lower level of processing
  - *operates on the minimal processable set of data covering a given sky area*
- Requirements: **Robust**, **Reliable**, **Scalable**, **Maintainable**

Logical Architecture

- A **Euclid Archive System** (EAS)
  - *Central Metadata Repository*
    inventories, indexes and localizes distributed data
  - *Distributed Storage over the SDCs*
    balance between data availability, data transfers and redundancy
- A set of services (middleware) **decoupling** SGS components
  - *e.g. metadata query and access, data localization and transfer, data processing M&C, …*
- An **Infrastructure Abstraction Layer** (IAL)
  - *decouple data processing software and underlying IT infrastructure*
- **Monitoring&Control** (M&C) **and Orchestration** layers
  - *responsible for distributing data and processing among the SDCs.*

Science Working Group

Cosmology:

- Weak Lensing
- Galaxy Clustering
- Theory
- Clusters of galaxies
- CMB Cross-correlations
- Strong Lensing

Legacy:

- Primerval Galaxies
- Galaxy and AGN evol.
- Nearby Galaxies
- Milky Way
- Planets
- SNs & Transient

Cosmological Simulations

Science Working Group (SWG)

- The science activities performed by **Science Working Groups** *[using Level 3 data]*.
- People involved in science analyses participate to different **Working Groups**, having a specific task.

Work Packages

Cosmology WGs:

- Weak Lensing
- Galaxy Clustering
- Theory
- Clusters of galaxies
- CMB Cross-correlations
- Strong Lensing

Legacy WGs:

- Primerval Galaxies
- Galaxy and AGN evol.
- Nearby Galaxies
- Milky Way
- Planets
- SNs & Transient

Cosmological Simulations WGs

Science Working Group (SWG)

Each WG task is divided in several **Work Packages**.

INFN groups, beside instrument commitments, are currently involved in the **CMB cross-correlations WG** *(more if other groups, hopefully, join in)*

CMB Cross-correlations

Work Packages

- WP1: Integrated Sachs-Wolfe (ISW)
- WP2: Rees-Sciama
- WP3: Lensing Extraction
- WP4: CMB lensing likelihood
- WP5: Cross-Correlation estimators
- WP6 SZ maps and Euclid Cluster Cross-Correlation
- WP7: Validation

COSMO_WNEXT

- **COSMO_WNEXT** is an INFN GRII research program, which includes activities in two ESA space missions (Euclid & Planck)
  from Bologna and Padova Divisions : ~ 20 people

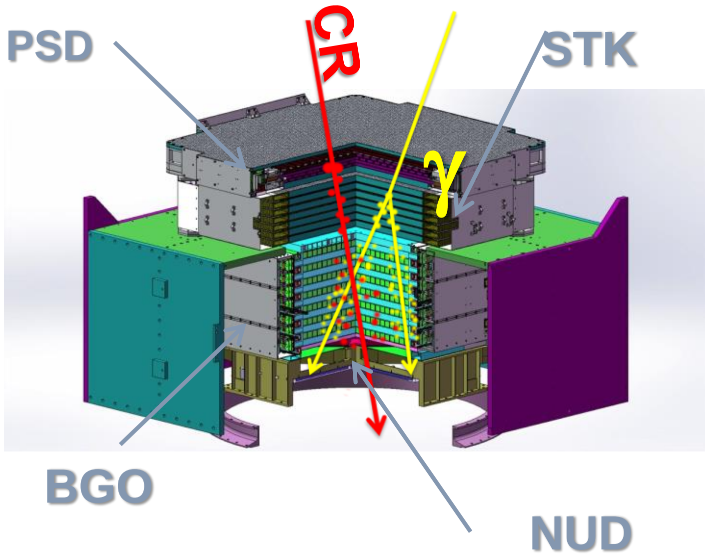
- In Euclid
  - responsibility at instrument level (AIV Warm Electronics)
  - Data analysis & simulation:
    - *mildly non-linear large scale structure simulations*
    - *estimation of the tomographic cross-correlation power spectra between CMB and density fields derived from Euclid galaxy*

- Necessity of HPC resources (possibly at **INFN-CNAF**):
  - ***O(1k) cores (physical)***
  - ***Filesystem GPFS ~400 TB***
  - ***Infiniband 40 Gbps (nodes and storage)***

DAMPE
Dark Matter Particle Explorer

DAMPE

- One of the Five **Approved Satellite Missions** of the Chinese Academy of Sciences (CAS)
- Goal:
  - **Search for Dark Matter** signatures with e, γ
  - Study of cosmic ray spectrum and composition
  - High energy gamma ray astronomy
- How:
  - 5 GeV - 10 TeV **e, γ**
  - 100 GeV - 100 TeV **CR**
  - **excellent energy resolution and tracking precision**
- Lifetime > 3 years

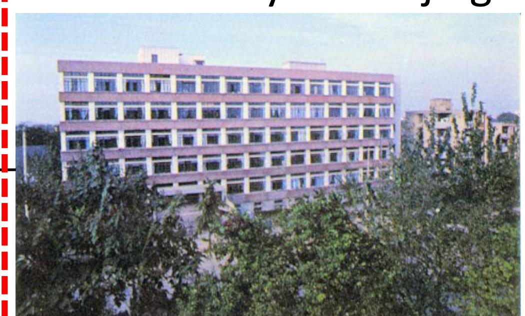


DAMPE Data Path

Chinese space communication system

China National Space Administration (CNSA) center in Beijing

Purple Mountain Observatory in Nanjing



deputed center for DAMPE data production

CNAF (Italy)

Local Centers: Perugia, Geneva, Bari, Lecce

DAMPE Data Transfer

- ~**100 GB/day** (~ 36 TB/year) data streams **PMO -> CNAF** *(gridFTP)*

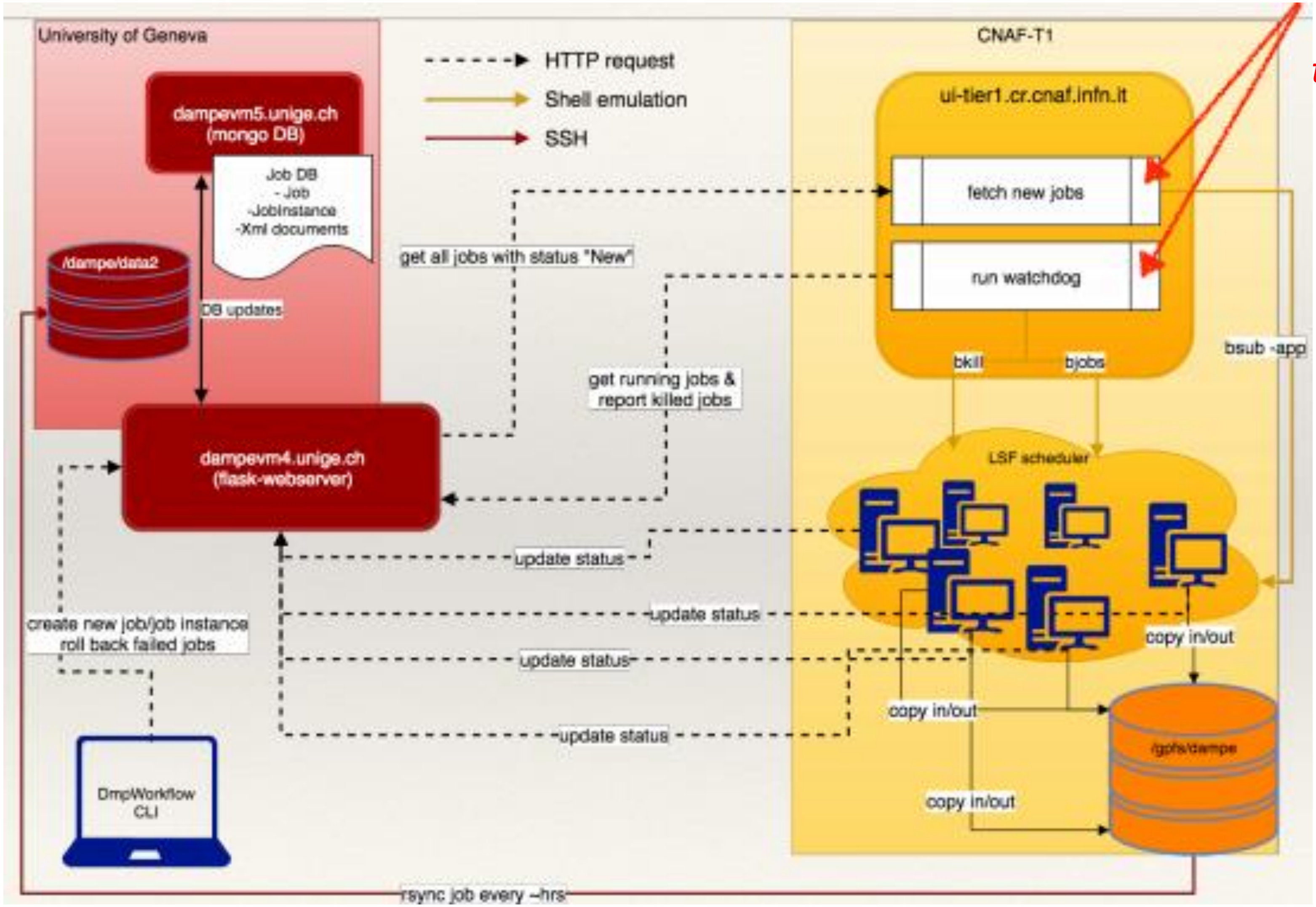
Data Streams	Description	Transfer rate @ CNAF
1A	Raw data	
1B	**Raw data in ROOT format**	**~15 GB/day**
1C/1D	Pedestal, MIPs and Observation Science Packets	
1F	**Raw data in ROOT format with orbital and slow control information**	**~15 GB/day**
1Q	BGO calibration data and plots	
2A	**Reconstructed data**	**~70 GB/day**
CAL	**Calibration data**	**~400 MB/day**

- Data at CNAF will be accessed from local centers via AFM (Active File Manager) of GPFS (Perugia, Bari) and via Gridftp (Geneva)

Monte Carlo Production

- Monte Carlo **production at CNAF** to simulate DAMPE performances in orbit:
  - Simulation of the *orbit*
  - Simulation of *real particles fluxes*
  - Simulation of *geomagnetic effect*
  - Simulation of the interactions inside the *detectors*
- Custom **Workflow Management System** at the University of Geneva (flask + MongoDB + python scripts)

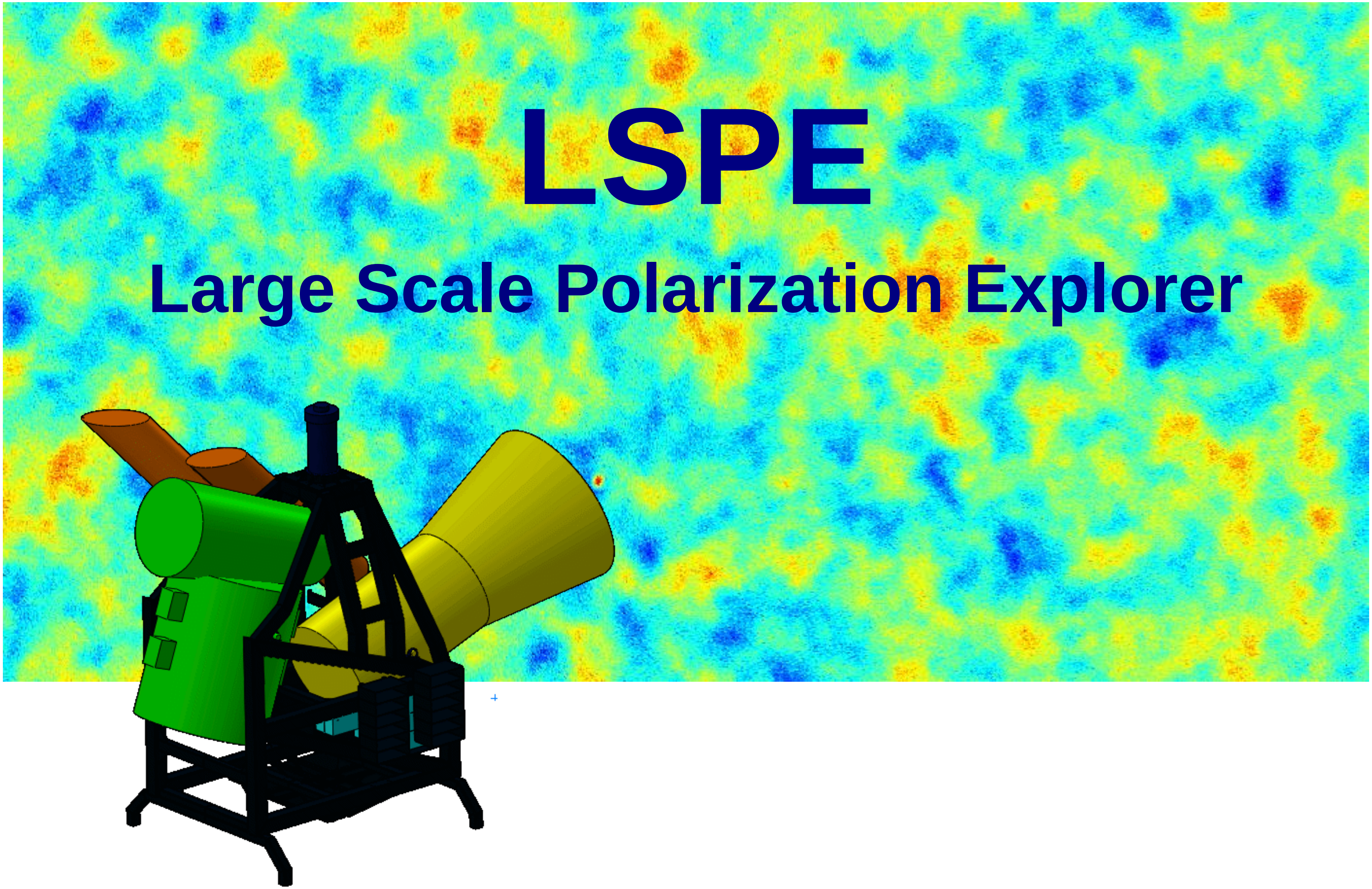
DAMPE WMS Prototype Scheme



Currently screen terminal

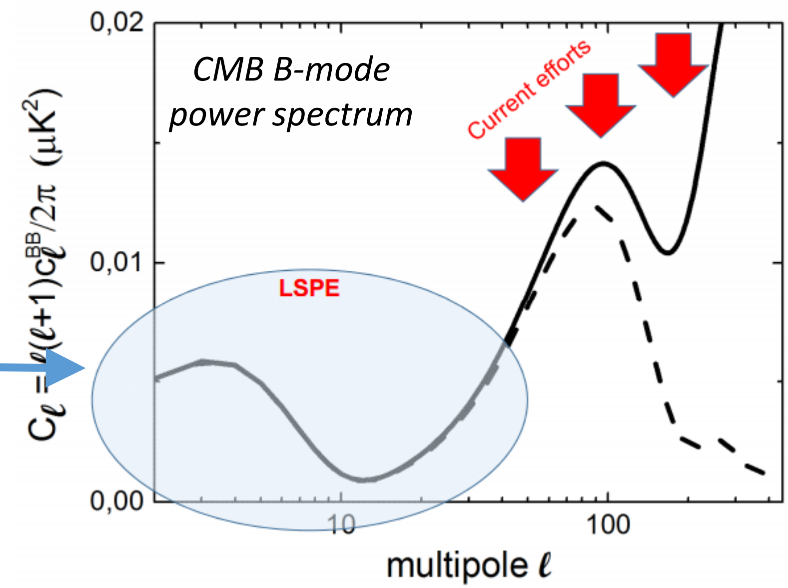
LSPE

Large Scale Polarization Explorer



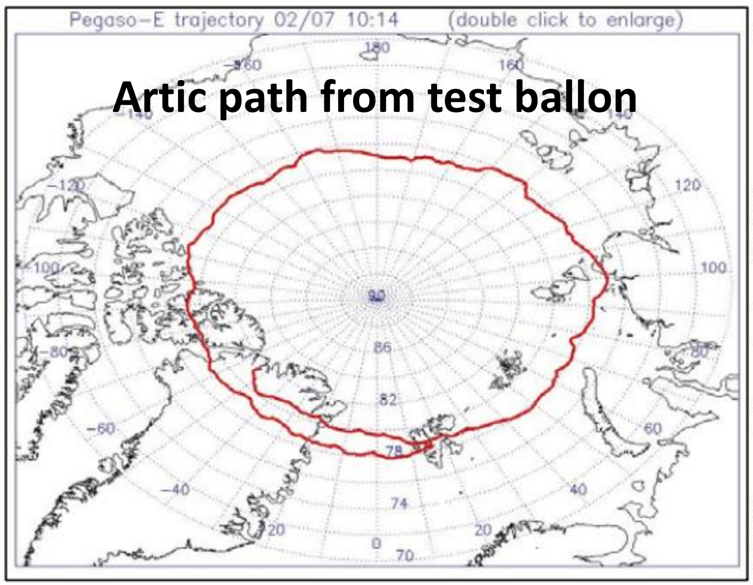
LSPE

- Large Scale Polarization Explorer:
  - measure the **polarization of CMB** at large angular scales
  - targeting the **reionization peak of B-mode** power spectrum
  - spinning (3 rpm) **stratospheric balloon** payload
  - flying long duration (15 days) in polar night

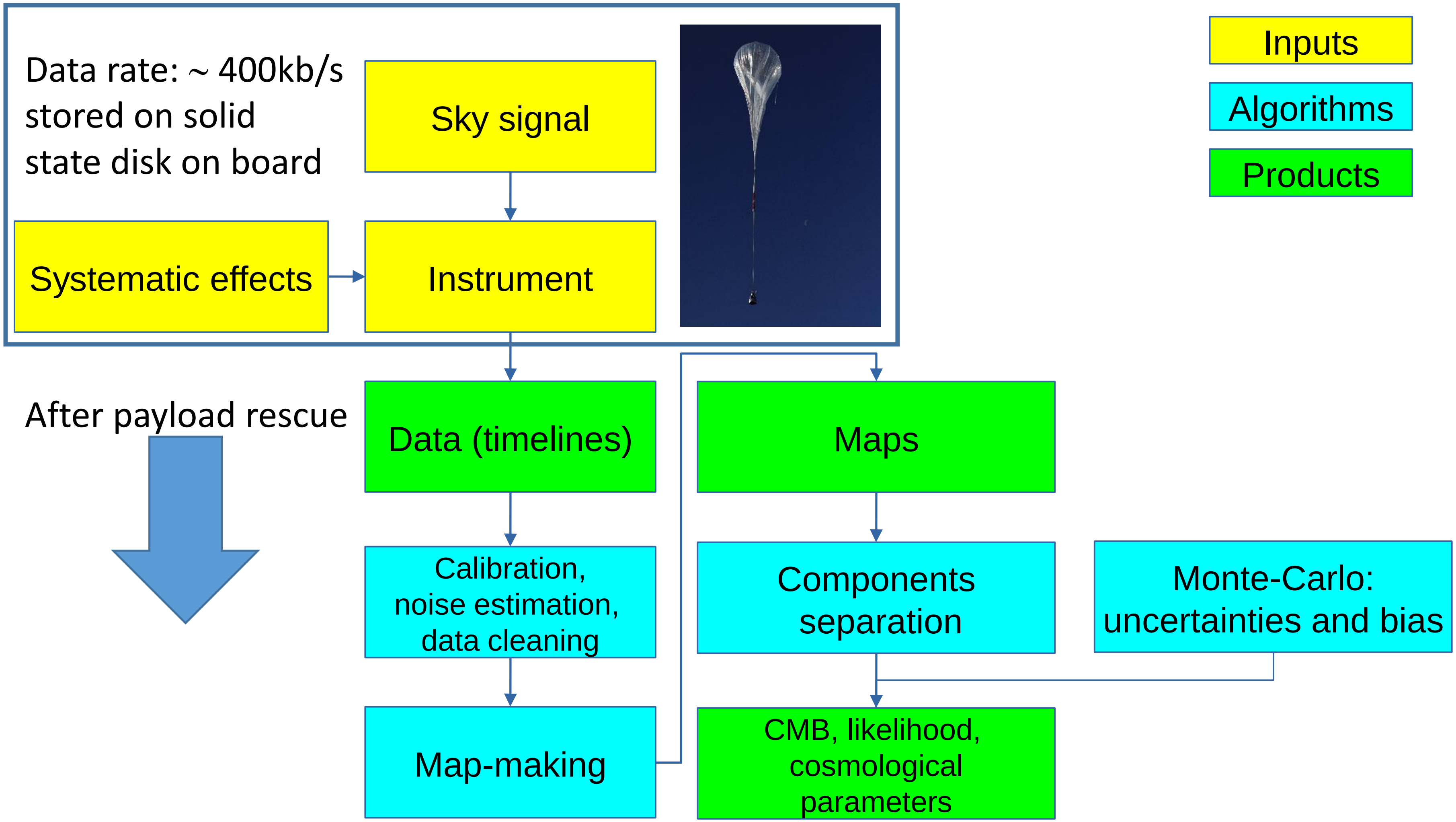


- Frequency coverage: **40 – 250 GHz**
  (5 channels, 2 instruments: STRIP & SWIPE)

- Sky coverage: **25% of the sky**



LSPE Data flow



Simulation & Analysis

- **Instrument simulator** is essential:
  - in the pre-launch phase to control of systematic effects
  - in post flight analysis to de-bias the cosmological estimators from systematic contributions
- The simulator is a parallel (**MPI**) code. One detector (326 in SWIPE) per task. **16 GB RAM** needed per detector.
- Data size produced by simulation are dominated by the signal and noise time ordered data (TOD) simulation, equal to **342 TB**
- **Data Analysis**: Map-making and power spectrum estimation
- Needed HPC facility, preferably at CNAF:
  - ~ 650 physical cores
  - ~ 350 TB GPFS
  - Infiniband 40 Gbps (node and storage)
  - Currently simulator runs in «opportunistic mode» at NERSC HPC facility

PaMeLa

a **P**ayload for **A**ntimatter **M**atter **E**xploration and **L**ight–nuclei **A**strophysics

PAMELA detectors

Main requirements → high-sensitivity antiparticle identification and precise momentum measure

Time-Of-Flight
plastic scintillators + PMT

- -Trigger;
- -Albedo rejection;
- -Mass identification up to 1 GeV;
- -Charge identification from dE/dX.

Electromagnetic calorimeter
W/Si sampling (16.3 X_0, 0.6λ_I)

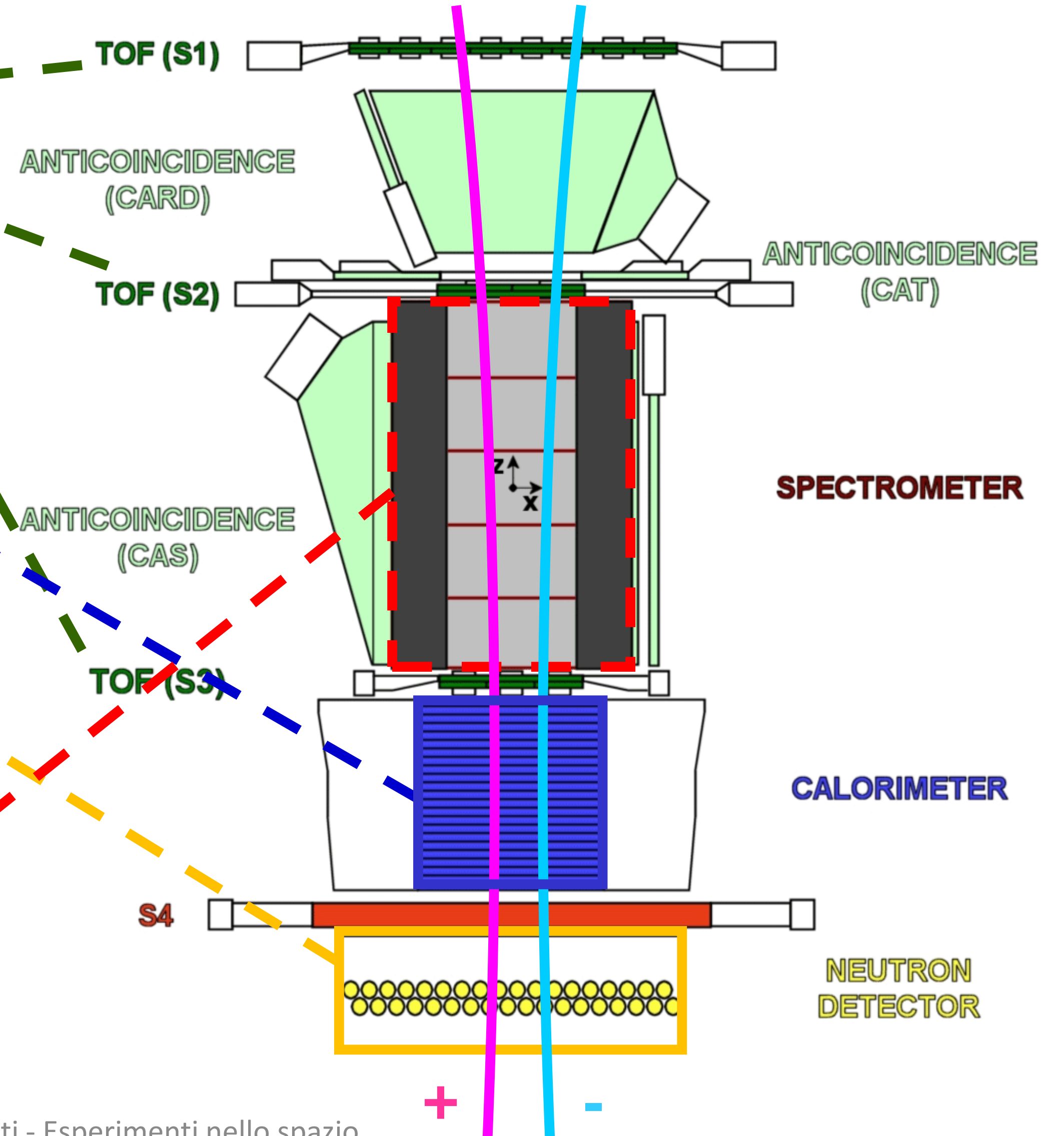
- Discrimination e^+/ p, pbar/e^- (shower topology)
- Direct E measurement for e^-

Neutron detector &
Shower-tail catcher (S4)

- -High-energy e/h discrimination

Spectrometer microstrip silicon tracking system + permanent magnet

- •Magnetic rigidity (R = pc/Ze)
- •Charge sign
- •Charge value from dE/dx



PAMELA

Contents lists available at ScienceDirect

Physics Reports

journal homepage: www.elsevier.com/locate/physrep

The PAMELA Mission: Heralding a new era in precision cosmic ray physics

O. Adriani[a,b], G.C. Barbarino[c,d], G.A. Bazilevskaya[e], R. Bellotti[f,g], M. Boezio[h], E.A. Bogomolov[i], M. Bongi[a,b], V. Bonvicini[h], S. Bottai[b], A. Bruno[f,g], F. Cafagna[g], D. Campana[d], R. Carbone[d,h], P. Carlson[j,k], M. Casolino[l], G. Castellini[m], M.P. De Pascale[l,n,1], C. De Santis[l,n], N. De Simone[l], V. Di Felice[l], V. Formato[h,o], A.M. Galper[p], U. Giaccari[d], A.V. Karelin[p], M.D. Kheymits[p], S.V. Koldashov[p], S. Koldobskiy[p], S.Yu. Krut'kov[i], A.N. Kvashnin[e], A. Leonov[p], V. Malakhov[p], L. Marcelli[n], M. Martucci[n,q], A.G. Mayorov[p], W. Menn[r], V.V. Mikhailov[p], E. Mocchiutti[h], A. Monaco[f,g], N. Mori[a,b], R. Munini[h,j,k,o], N. Nikonov[i,l,n], G. Osteria[d], P. Papini[b], M. Pearce[j,k], P. Picozza[l,n,*], C. Pizzolotto[h,s,t], M. Ricci[q], S.B. Ricciarini[b,m], L. Rossetto[j,k], R. Sarkar[h], M. Simon[r], R. Sparvoli[l,n], P. Spillantini[a,b], Y.I. Stozhkov[e], A. Vacchi[h], E. Vannuccini[b], G.I. Vasilyev[i], S.A. Voronov[p], J. Wu[j,k,u], Y.T. Yurkin[p], G. Zampa[h], N. Zampa[h], V.G. Zverev[p]

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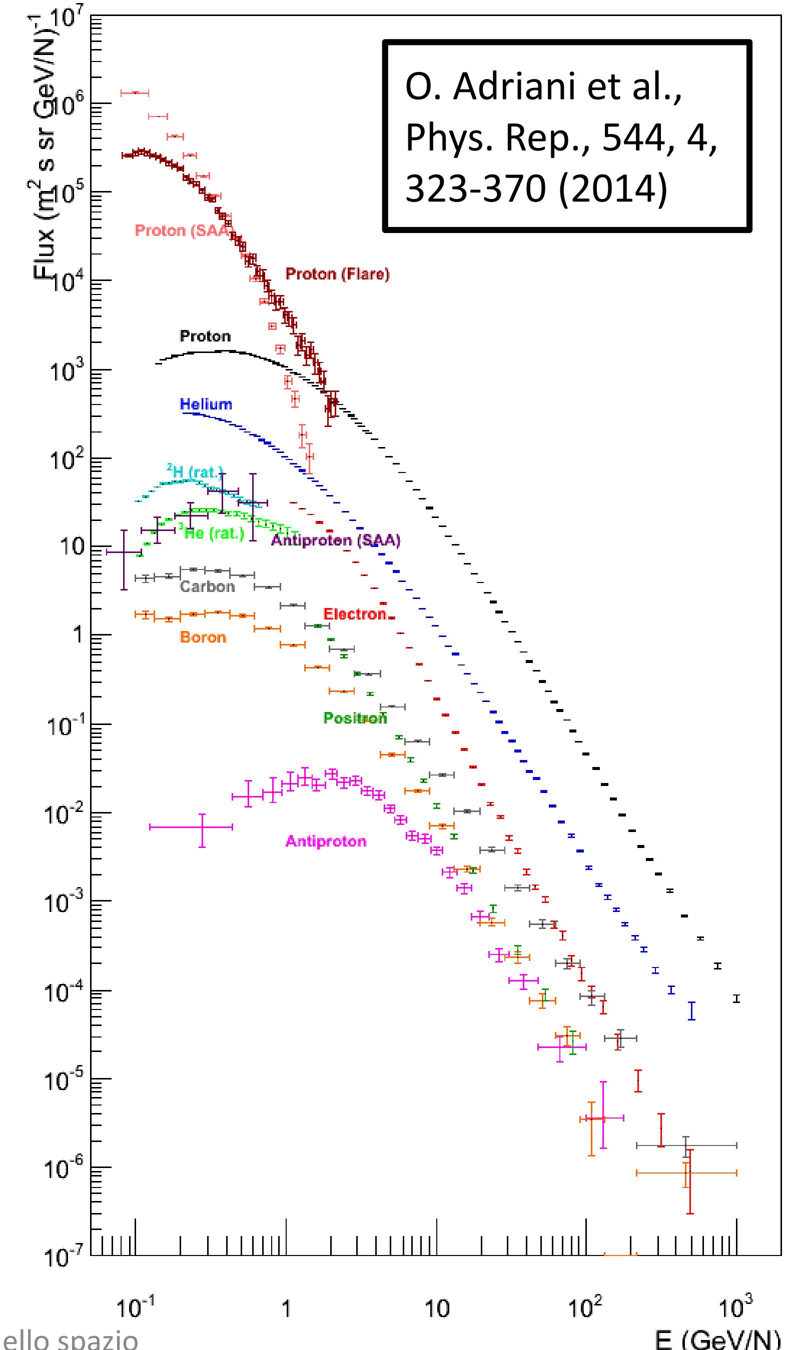
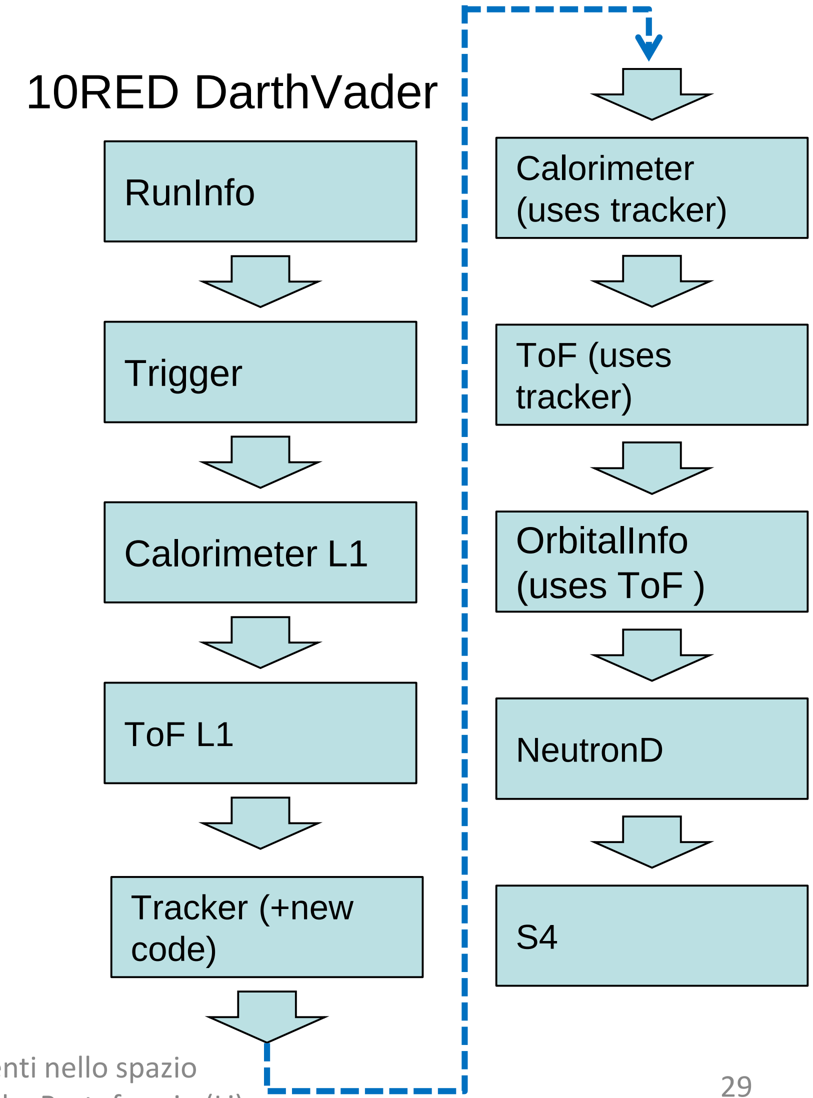


O. Adriani et al.,
Phys. Rep., 544, 4,
323-370 (2014)

Offline & Real time data reduction

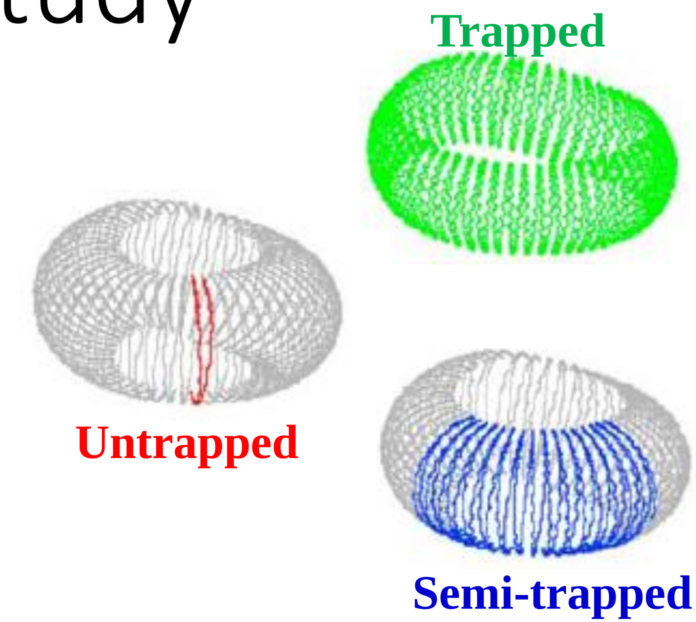
- A «*Real Time*» data reduction is performed as soon as data are available after a download, for quicklook and early alerts for specific event topology or space wheater analysis (solar events).

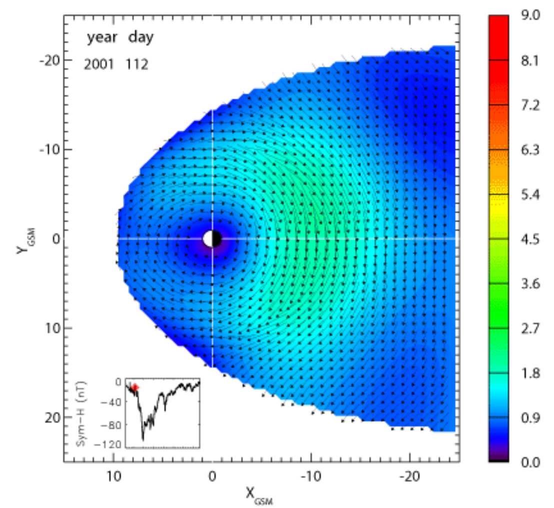
- An *offline* data reduction campaign is performed to produce an updated reference data sets, with more refined calibrations and algorithms.



Solar Flare Study

- Particle detected classified as: **trapped**, **untrapped** and **semi-trapped**.
- To evaluate contribution by different families: **trajectory backtracking techniques** -> Billions of trajectories to simulate
- Same techniques used to study particle from solar events (**flares**)
  details in O. Adriani et al. [ApJL 801 (2015) L3]
- **massive campaign of analysis**, using this computing intensive methods, for every solar event during the mission lifetime, is on going.

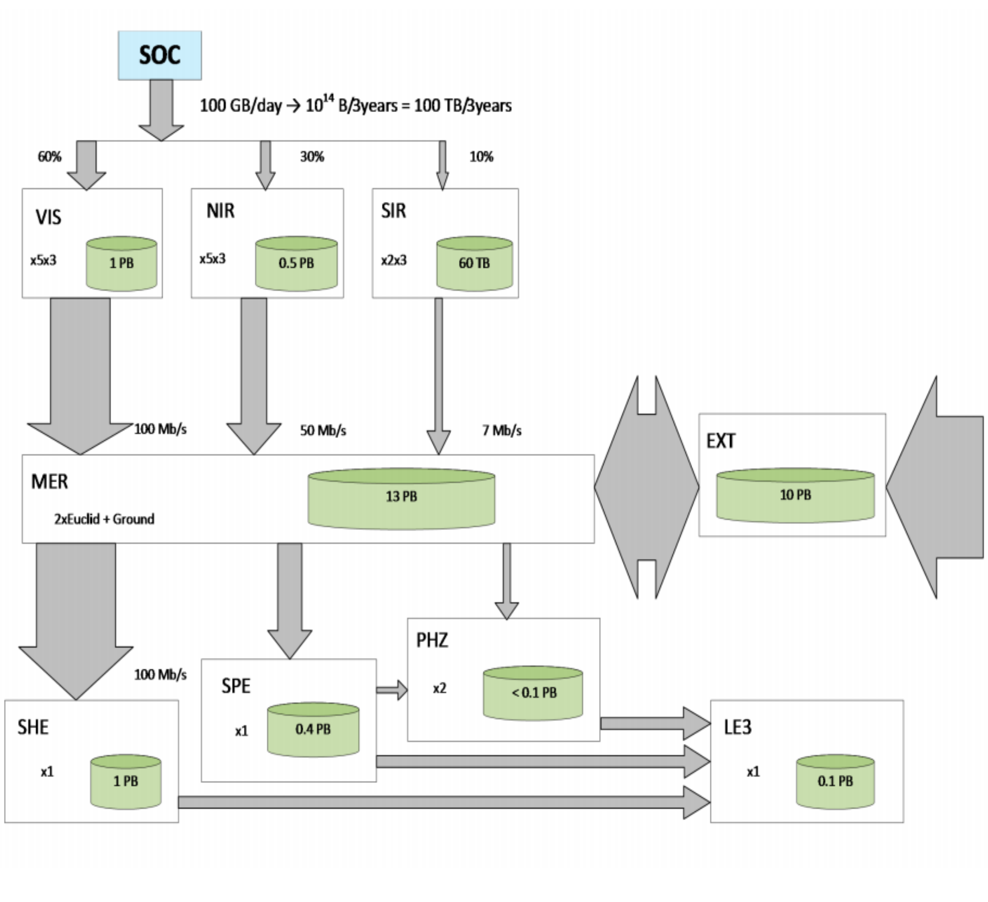




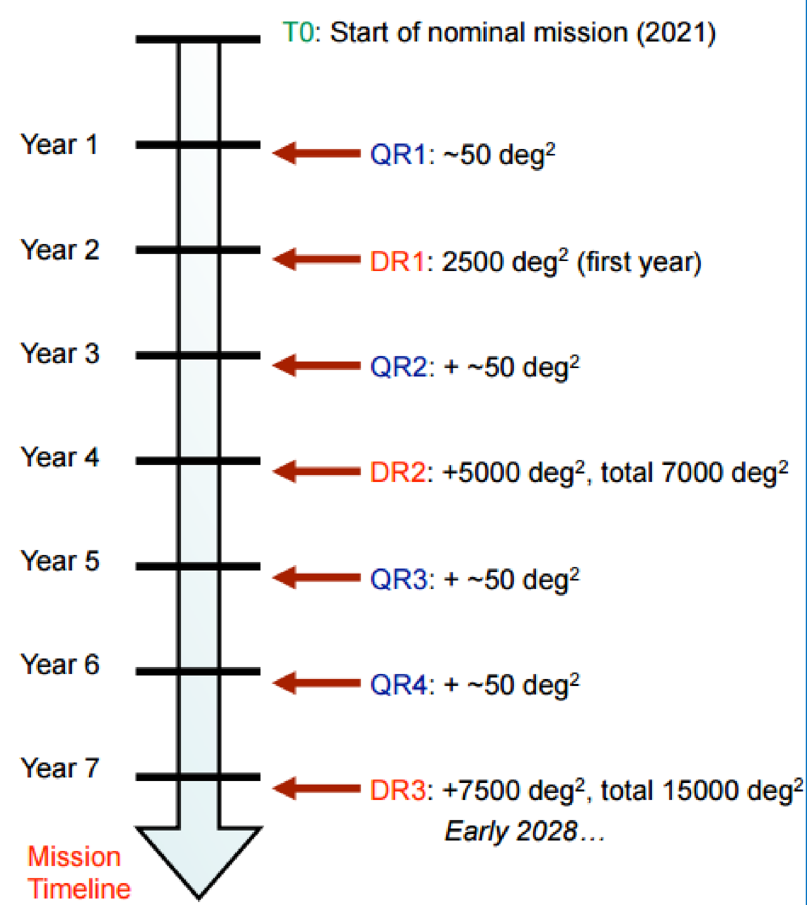
Spares

Data

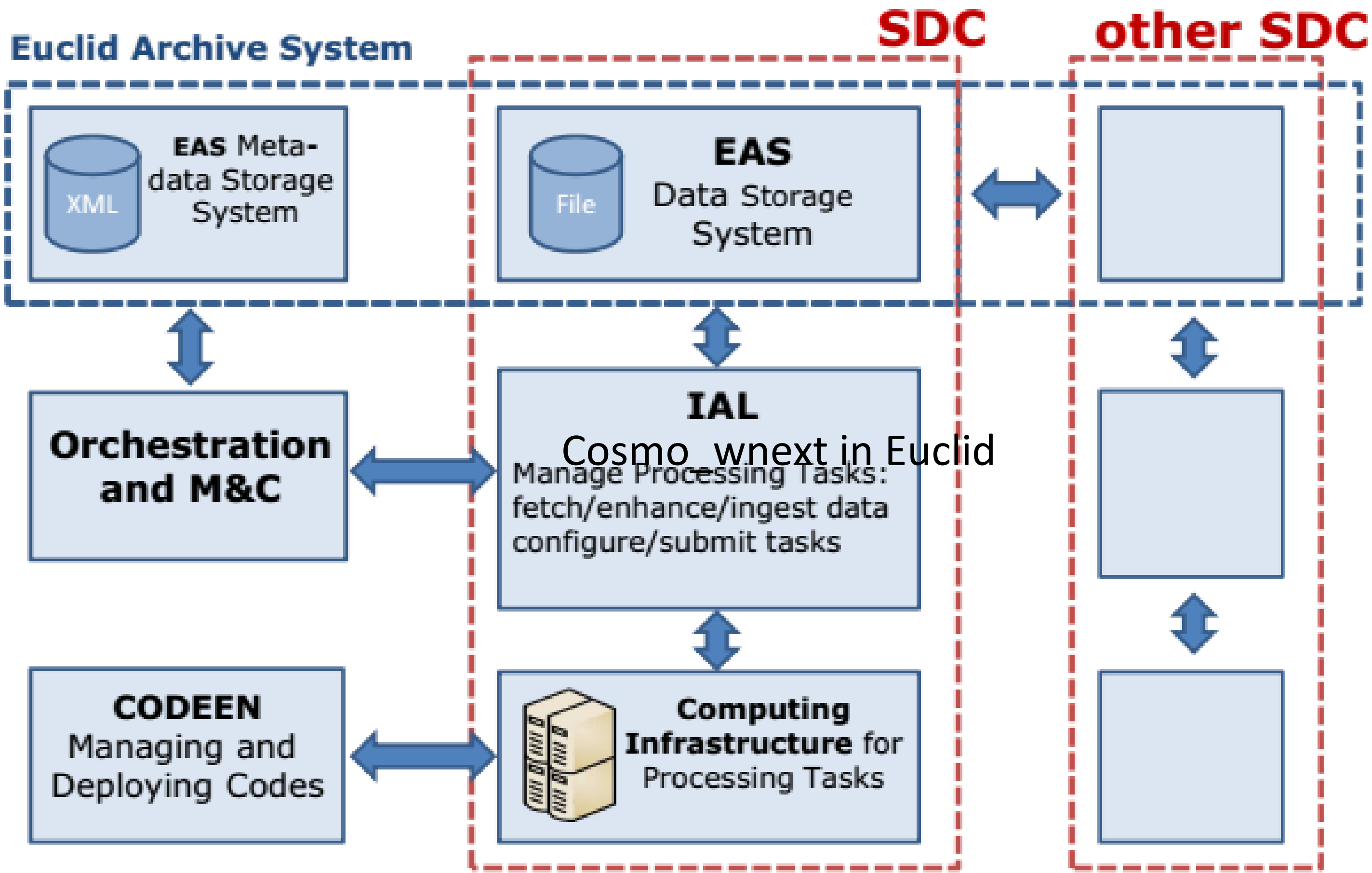
Expected data flow among PF



Planned data release



Cosmo_wnext in Euclid



Development Environment

Common tools

Different domains

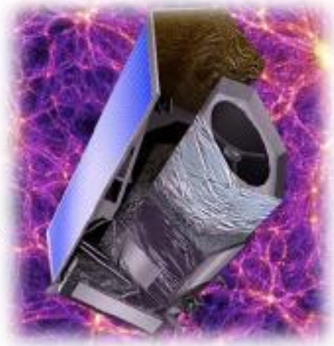
- Development environment
  - ✓ CODEEN (high-level centralized for dev/build/doc/packaging etc…)
  - ✓ EDEN (encompasses all common standards and tool for developers)
  - ✓ LODEEN (Virtual machine pre-installed with EDEN tools)

- Infrastructure environment : deployment/installation

- Scientific environment :
  - ✓ common (third parties) scientific libs
  - ✓ common scientific packages (developed once and shared among different processing functions)
  - ✓ Mission Data Base : data to be shared (physical constants, instrumental parameters, environment parameters,…)

Euclid Operations: In Flight

4 hrs/day



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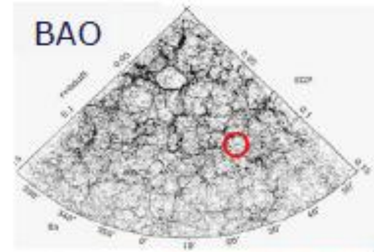
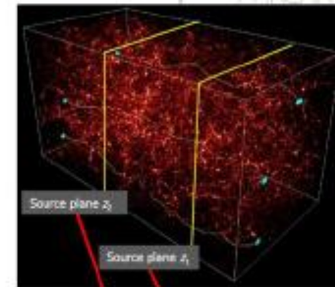
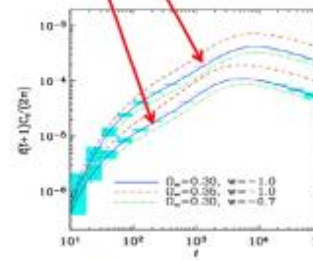


1.5 billion sources with shapes, 10 slices





Deep Space Antenna
(Spain

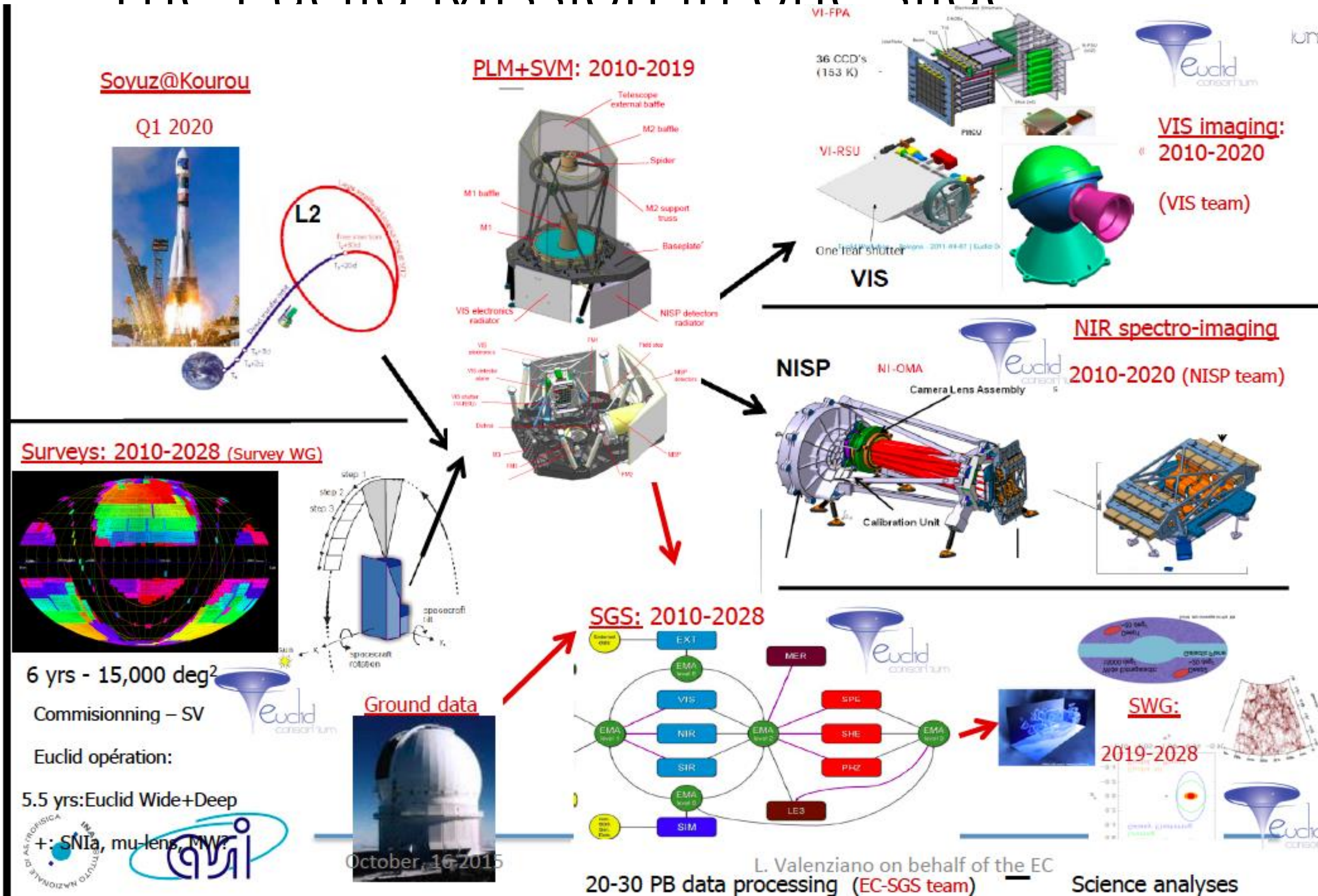
Mission Operation Center
(ESA/ESOC-Germany)

Science Operation Center
(ESA/ESAC–Spain)

SDCs
IOTs

EAS
(archive)

The Euclid Mission in one slide



SDC - Italia

La SDC italiana si basa sul cluster DHTCS a INAF-OA_TS.
Si tratta di un cluster HPC basato su Linux con circa 800 core e 8 GB di RAM per core.
I nodi di elaborazione sono collegati fra loro e al GPFS (400 TB di storage parallelo) con 40 Gbps InfiniBand.

Secondo le stime SGS esistenti, la prevista rampa in tempo di risorse fornite è tale da avere 7 kcores e 35 PB di storage entro il 2027.

Data size

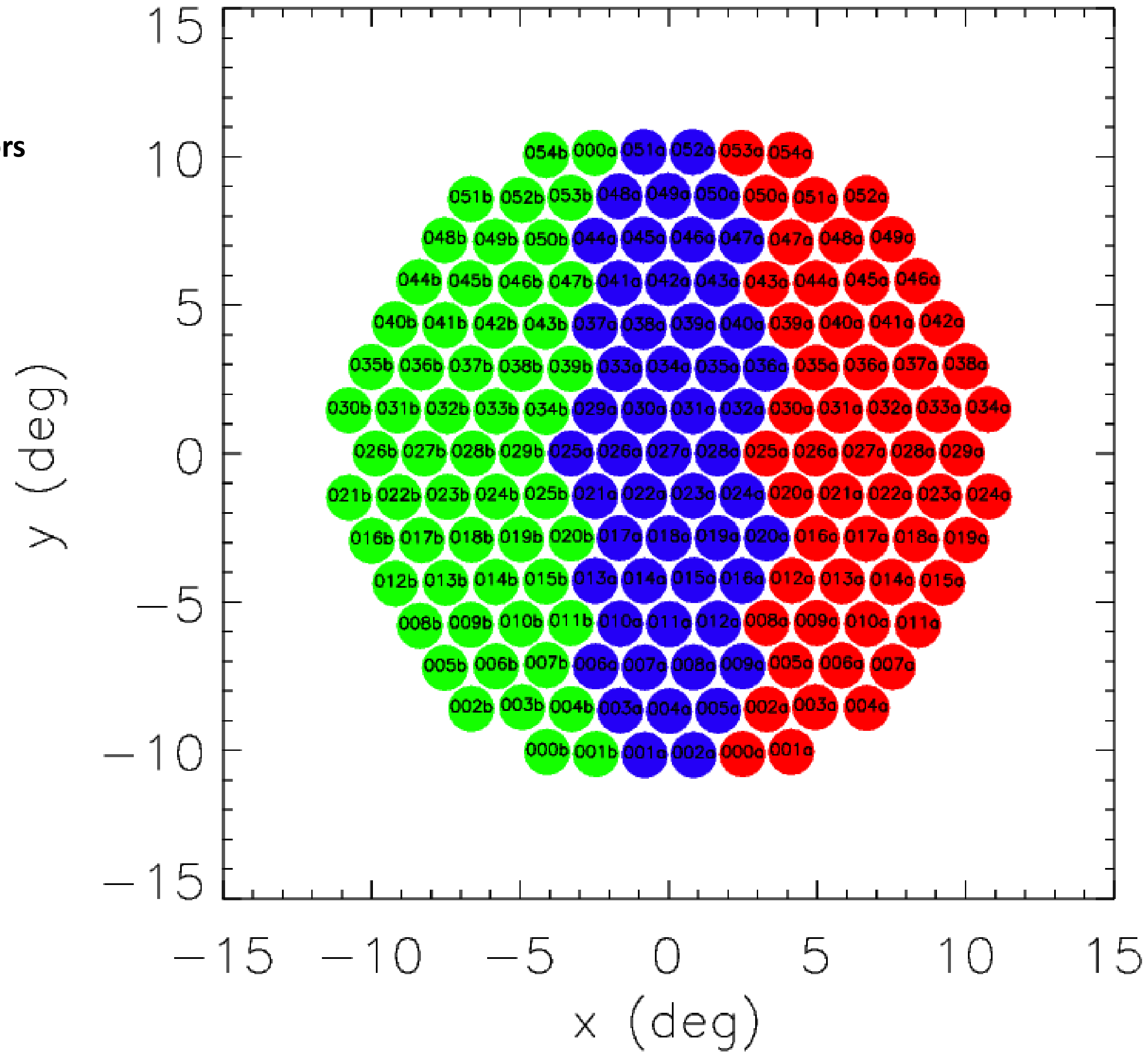
Data type	Parameter	Value	Unit
TOD	Sampling	100	Hz
	detectors	330	
	duration	15	gg
	data	$\sim 4.3 \cdot 10^{10}$	
	byte per data	4	
	Total	117	GB (INT)
ATTITUDE	sensors	4	
	data	$5.2 \cdot 10^{8}$	
	byte per data	4	
	Total	2	GB (INT)
MAPS	nside	256	
	Map pixels	786432	
	pixel_TQU	2359296	
	coverage	0.3	
	data_map	707788.8	
	Total	5.66	MB (double precision)
Covariance†	nside	64	
	Map pixels	49152	
	pixel_TQU	147456	
	coverage	0.2	Useful sky fraction
	Covariance matrix	$\sim 8.7 \cdot 10^{8}$	
	Total	6.957	GB (double precision)
Monte Carlo	realizations	1000	
	tod signal	171	TB
	tod noise	171	TB
	maps signal	5.66	GB (double precision)
	maps noise	5.66	GB (double precision)

† This is the noise covariance matrix of the map, expressed in pixel space.

LSPE
Large Scale Polarization Explorer

SWIPE - Focal plane

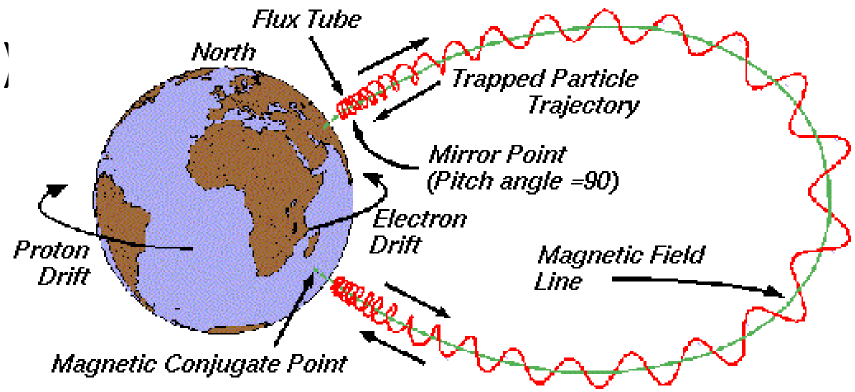
- **2 focal planes**
- **Total: 163*2 = 326 detectors**



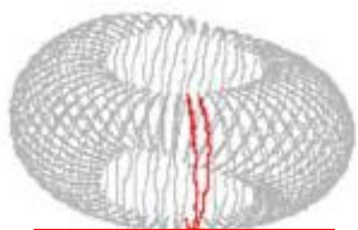
- **140GHz: 55*2 = 110 detectors**
- **220GHz: 56*2 = 112 detectors**
- **240GHz: 52*2 = 104 detectors**

Under cut-off (anti)particles

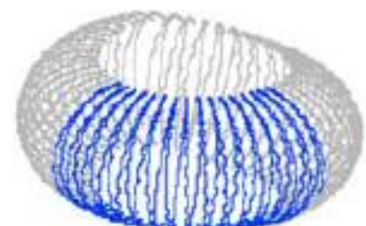
- Thanks to the semi-polar (70 deg inclination) and elliptical (350-610 km altitude) satellite orbit, PAMELA is able to perform energy spectra and particle composition measurements in different regions of the terrestrial magnetosphere.
- A complex study of the trajectories is needed to clearly separate different particle families: **trapped**, **untrapped** and **semi-trapped,** depending on their lifetime moving along the magnetic field lines in the lower magnetosphere.
- The angular distribution of these particle is anisotropic. For this, in order to calculate fluxes, the detector exposition can be calculated only via a complex geometrical simulation of the accepted trajectories.



Trapped



Untrapped

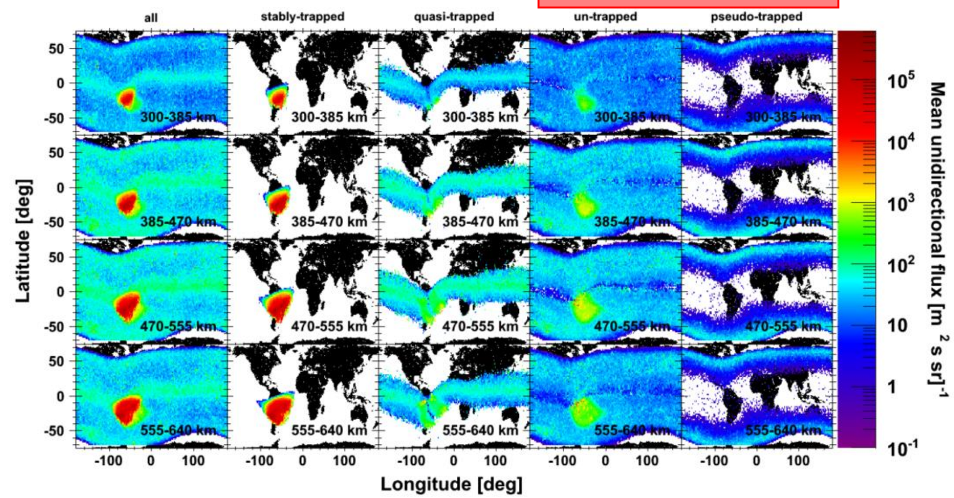


Semi-trapped

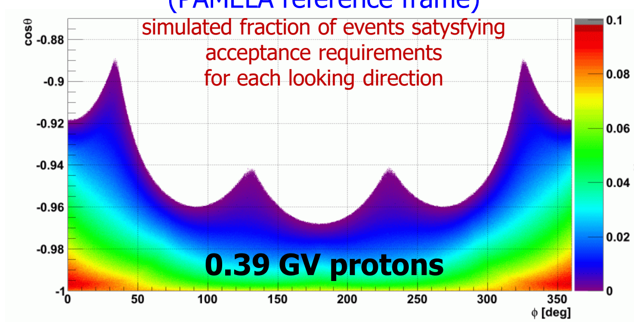
Flux and track reconstruction

- In order to calculate **anisotropic** fluxes the exposition factor must be calculated, using **trajectory backtracking techniques**, for every potential direction of arrival and energy bin, taking into account the satellite position and orientation respect to the magnetic field lines. This must be done in every system of reference the fluxes must be calculated.
- Billions of possible trajectories must be simulated to calculate the matrices of exposition values in each one of the system of references to be used for model or other measures comparisons.

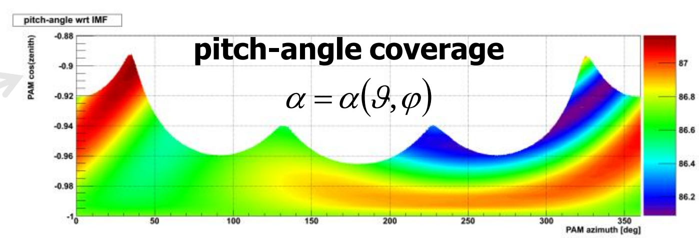
Fluxes

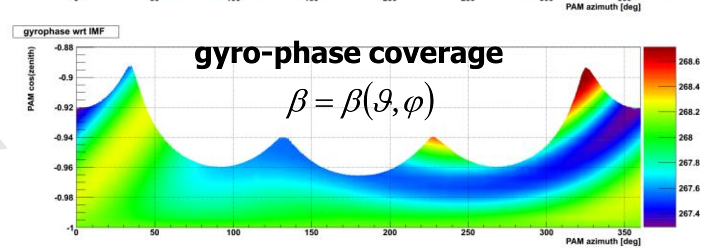


cos(zenith) vs azimuth
(PAMELA reference frame)

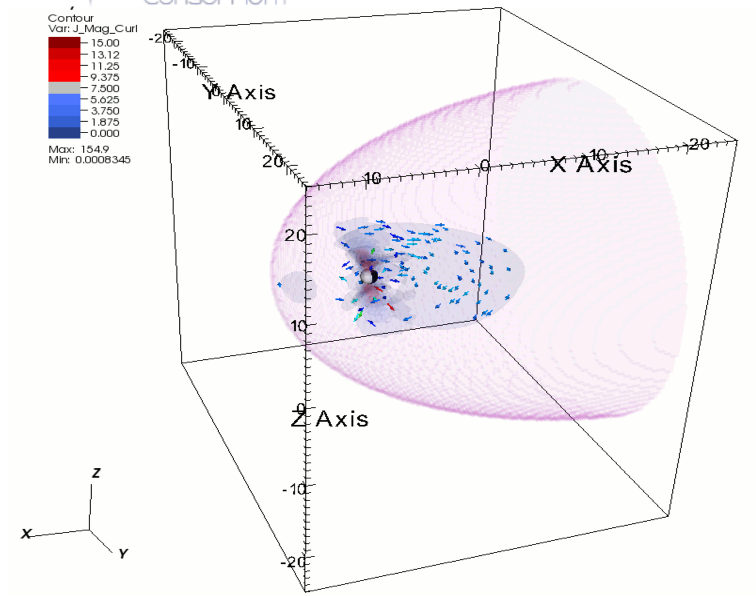


BACK-
TRACING





Backtracing solar particles



- The same techniques can be used to measure angular distribution and analyze anisotropies related to **solar** events (**flares**), taking into account for the effect of the particle propagation in geomagnetic field.
- To determine asymptotic directions, particle trajectories are numerically traced backward through a model magnetosphere until they cross the magnetopause. The calculation also allows to evaluate geomagnetic cutoff rigidities and to separate protons of interplanetary (GCRs & SCRs) and atmospheric (trapped & albedo particles) origin

PAMELA data:
- spacecraft position & orientation, particle rigidity and direction, UT

IMF and Solar Wind parameters:
- high-resolution (5-min) OMNIWeb data

NASA/Goddard Space Flight Center

TRAJECTORY TRACING CODE

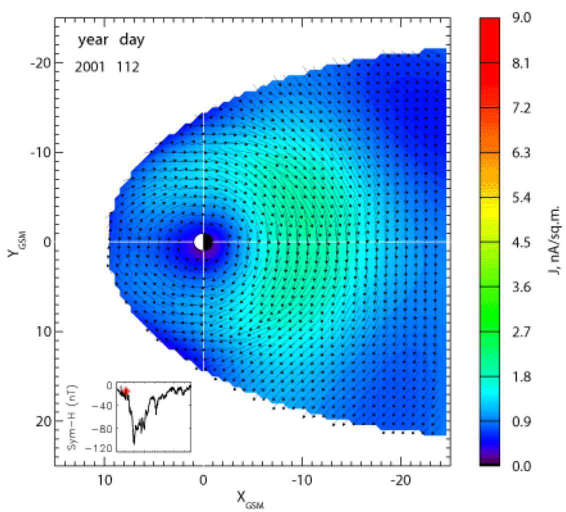
Runge-Kutta integration of motion equations
- ❖ Based on Smart & Shea (2000, 2005)

Realistic description of the geomagnetic field:
- internal sources: IGRF-11 model
- external sources: Tsyganenko models

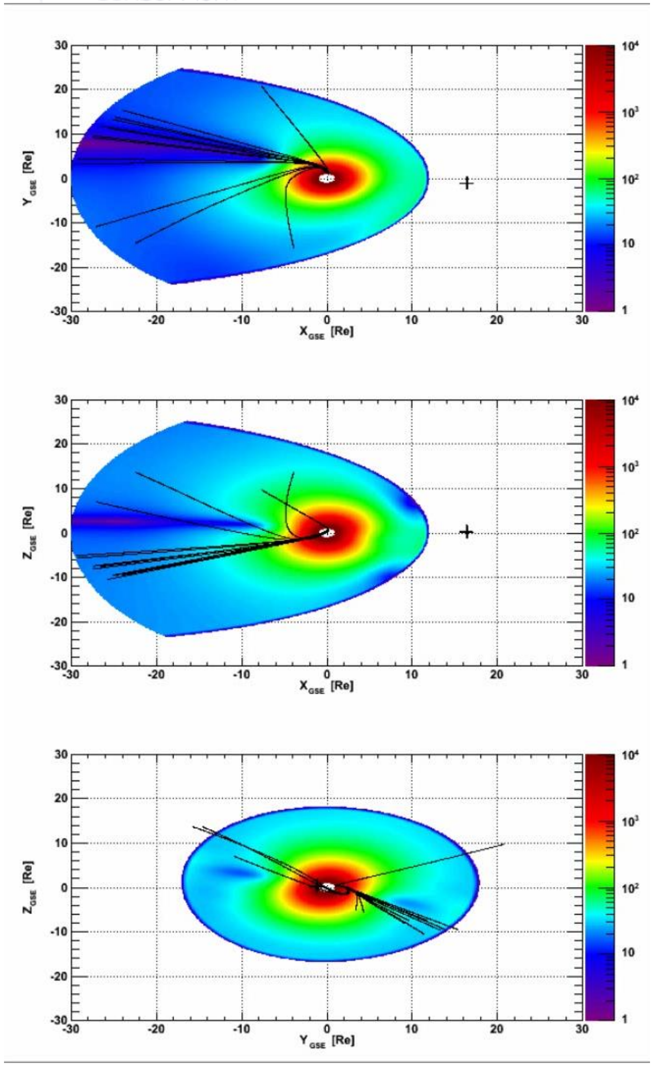
Interplanetary particles (SCR+GCR)
- ❖Asymptotic directions (pitch-angle distributions)
- ❖ Apparatus asymptotic exposition

Geomagnetically trapped & albedo particles
- ❖ Discarded

For more details: http://geomag_field.jhuapl.edu/model/



Solar flare particles



- Also in this case fluxes must be calculated during specific time interval (typically during the flares themselves), reconstructing tens of millions of trajectories for every event.
- Thanks to this analysis technique, just to give and example, during the 2012 May 17th event PAMELA observed 2 energy components with different pitch angle distribution:
  - **High rigidity component** consistent with NM where particles are field aligned -> Beam width ~40-60° (not scattered)
  - **Low rigidity component** shows significant scattering for pitch angles ~90°
- This is a major contribution to understand the nature of such kind of solar event and activity.
- PAMELA collaboration is undertaking a massive campaign of analysis, using this computing intensive methods, for every major solar event occurred during the mission lifetime.

See for example: Adriani et al., ApJL 801 (2015) L3